

**OPTICAL PICK-UP APPARATUS, LIGHT CONVERGING OPTICAL SYSTEM OF
OPTICAL PICK-UP APPARATUS, AND OPTICAL INFORMATION RECORDING
AND REPRODUCING METHOD**

BACKGROUND OF THE INVENTION

The present invention relates to an optical pick-up apparatus to record and reproduce the information onto the optical information recording medium having a plurality of information recording layers, in layer-like, and a light converging optical system of the optical pick-up apparatus, and optical information recording and reproducing method, and particularly to an optical pick-up apparatus to record or reproduce the information onto a laminated plurality of information recording layers, by using a luminous flux whose image side numerical aperture is not smaller than 1.0, using an evanescent light, a light converging optical system of the

optical pick-up apparatus, and optical information recording and reproducing method.

Recently, accompanied by putting to practical use of the short wavelength red semiconductor laser, a DVD (digital versatile disk) whose dimension is almost the same as the CD (compact disk) which is the conventional optical disk, that is, optical information recording medium, and whose capacity is largely increased and which is the high density optical disk, is developed, and put into the market, however, it is forecasted that, in near future, the higher density next generation optical disk is also comes into the market. In the optical system of the optical information recording and reproducing apparatus using such the optical disk as the medium, in order to intend to highly increase the density of the recording signal, or to reproduce the high density recording signal, it is required that the spot diameter which is light converged onto the recording medium through the light converging optical system is reduced. For such the requirement, as a solution means, the optical element using the principle of near field is proposed. The high NA of such the optical element is attained by using the evanescent light which is leaked from a solid immersion lens (?????) opposite

to the information recording surface, and for example, it is written in Japanese Tokkai No. 2000-99990.

However, when the information is recorded or reproduced to the optical information recording medium by using the evanescent light, because the evanescent light has the characteristic which rapidly attenuates corresponding to the distance, it is necessary that the information recording surface is formed on the surface of the optical information recording medium. However, a fact that the information recording surface is formed on the surface of the optical information recording medium, is that the protective layer can not be provided on the information recording surface. Accordingly, when it is used only in the hermetically shielded space, such the optical information recording medium can be used, however, for the removable optical disk such as the CD or DVD whose presupposition is that the user exchanges it by his hand, it is difficult that the information is recorded or reproduced by using the evanescent light.

Further, in order to intend to record or reproduce the high density information, the multi-layer type optical information recording medium in which the information recording layer is laminated, is also developed. When the recording or reproducing of the information is conducted onto

such the optical information recording medium, it is a problem how makes the information recording light including the evanescent light form an image onto each of information recording layers.

SUMMARY OF THE INVENTION

The present invention is attained in view of the forgoing conventional technological problem, and an object of the present invention is to provide an optical pick-up apparatus by which the high density optical information recording or reproducing can be conducted onto the multi-layer type optical information recording medium, a light converging optical system of the optical pick-up apparatus, and optical information recording or reproducing method.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a sectional view of a final optical element (almost semi spherical lens) constituting a portion of an objective lens of the present invention.

Fig. 2 is an outline structural view of an optical pick-up apparatus by which the recording or reproducing of the information can be conducted onto a multi-layer type

optical information recording medium which is an embodiment of the present invention.

Fig. 3 is an outline structural view showing an optical system according to the second embodiment.

Fig. 4 is an outline structural view showing an optical system according to the third embodiment.

Figs. 5(a) and 5(b) each is a view showing the relationship between the final optical element and diaphragm according to the fourth embodiment.

Figs. 6(a) and 6(b) each is a view showing the relationship between the objective lens and diaphragm according to the fifth embodiment.

Figs. 7(a) and 7(b) each is a view showing a light converging optical system according to the sixth embodiment.

Figs. 8(a) and 8(b) each is a view showing the light converging optical system according to the seventh embodiment.

Figs. 9(a) and 9(b) each is a view showing a light converging optical system according to the eighth embodiment.

Fig. 10 is a view showing an objective lens composition according to another embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Hereinafter, the structure to attain the above object will be explained.

An optical pick-up apparatus of (1) is an optical pick-up apparatus which has a light source, and a light converging optical system to light converge onto any of information recording layers of the optical information recording medium having the laminated plurality of information recording layers, and in the optical pick-up apparatus in which the recording or reproducing of the information is conducted onto the optical information recording medium, because the light converging optical system records or reproduces the information onto the information recording layer by light converging the luminous flux whose image side numerical aperture is not smaller than the 1.0, onto the optical information recording layer, the high density optical information recording or reproducing can be conducted onto the optical information recording medium. In this connection, as such the light converging optical system, so called a solid immersion lens, SIL, or SIM (which will be described later), is included, but, it is not limited to this.

In the optical system of the conventional optical pick-up apparatus, it is difficult to attain more than the image side numerical aperture (NA) of 1.0. The reason will be described below. The image side numerical aperture is defined as $n \cdot \sin \theta$ (n is the refractive index of the medium of the image space, and the θ is a half angle of the maximum cone angle in the medium of the image space), however, in the optical pick-up apparatus, when the recording and reproducing of the information is conducted onto the recording medium rotating like the CD, the air layer absolutely exists between the optical system and the recording medium, and its refractive index n is 1. Further, because $-1 \leq \sin \theta \leq 1$, the NA is 1 at the maximum, and in the actual image formation, the NA can only have a value not larger than 1.

As described above, in the optical pick-up apparatus, on the presupposition that the air layer exists between the optical system and the optical information recording medium, when the image side numerical aperture (NA) can attain more than 1, because the spot diameter in the information recording layer can be reduced very small, the recording density of the optical information recording medium is increased, and while intending to reduce the size of the

recording medium, the larger capacity information can be recorded or reproduced. Further, in the optical information recording medium having a plurality of information recording layers, an increase of the volume recording density can be intended.

In opposition to this, in the present invention, as an example of the optical system to attain the image side numerical aperture (NA), which is not smaller than 1, a light converging optical system using the effect of the near field is provided. Herein, the providing of the light converging optical system using the effect of the near field will be described below. Fig. 1 is a sectional view of the final optical element (almost semi-spherical lens) constituting a portion of the light converging optical system of the present invention. The luminous flux incident to the almost semi-spherical lens transmits within the range of the first predetermined angle θ_1 , and is irradiated onto the recording medium RM. However, for the luminous flux exceeding the first predetermined angle θ_1 , it is totally reflected on the lower surface of the almost semi-spherical lens HL, and as the result, it is said that the luminous flux is not effectively irradiated onto the recording medium RM.

Herein, when the light is totally reflected on the lower surface of the almost semi-spherical lens HL, there is a phenomenon that the evanescent light leaks out to the recording medium RM. Such the effect is called the near field effect, and the leaked-out light is called the evanescent light E. The evanescent light E has the characteristic that, after it is emitted from the almost semi-spherical lens HL, as the distance is larger, the light exponentially attenuates. Accordingly, when the distance Δ between the lower surface of the almost semi-spherical lens HL and the upper surface of the recording medium RM is larger, the evanescent light E attenuates and it can not be effectively used for the recording or reproducing of the information. However, when it is set that the distance Δ between the almost semi-spherical lens HL and the upper surface of the recording medium RM is smaller, (for example, lower than the wavelength of the transmitted light), because, before the evanescent light E attenuates, the light reaches the recording medium RM, the light can be used for the recording or reproducing of the information. That is, when the recording or reproducing of the information is conducted by using the luminous flux within the range which exceeds the

first predetermined angle θ_1 and which is to the second predetermined angle θ_2 , and which is totally reflected, the light converging optical system whose image side numerical aperture (NA) is not smaller than 1.0 can be structured. In this connection, the light converging optical system is not only the above final optical element, but may also be structured of a plurality of optical elements. Further, when the distance Δ is smaller than the wavelength of the information recording light used for the recording or reproducing of the information, it can be effectively used before the attenuation of the evanescent light.

In an optical pick-up apparatus described in (2), because the light conversing optical system has the final optical element opposite to the optical information recording medium, and the final optical surface of the final optical element is in contact with the surface of the optical information recording medium, the luminous flux to a predetermined angle θ_2 is not totally reflected on the lower surface of the almost semi-spherical lens HL and transmits it, and the recording or reproducing of the information can be conducted.

In an optical pick-up apparatus described in (3), the light converging optical system has the final optical element opposite to the light information recording medium, and because the final optical surface of the final optical element approximates to the surface of the optical information recording medium by spacing the distance not larger than one fourth of the wavelength of the light source, the recording or reproducing of the information can be conducted by using the evanescent light E.

In an optical pick-up apparatus described in (4), because a plurality of light converging optical systems are provided, and each of light converging optical systems is used for recording or reproducing of the information for respectively different information recording layers, when the recording or reproducing of the information is conducted onto each of information recording layers of the multi-layer type optical information recording medium, the aberration correction corresponding to each layer can be independently conducted, and when the recording or reproducing of the information is conducted onto the different information recording layers, an appropriate and quick recording or reproducing of the information can be conducted.

In an optical pick-up apparatus described in (5), the apparatus has a selection means to select the information . recording layer to be recorded or reproduced from a laminated plurality of information recording layers, and because the recording or reproducing of the information is conducted on the information recording layer selected by the selection means, the recording or reproducing of the information can be appropriately conducted on each of information recording layers of the multi-layer type optical information recording medium.

In an optical pick-up apparatus described in (6), the light converging optical system has at least 2 final optical elements, and each of final optical elements is used for the recording or reproducing of the information onto the respective different information recording layers, and when the selection means selects any one of the plurality of final optical elements, because the recording or reproducing of the information is conducted on the information recording layer corresponding to the selected final optical element, the aberration correction corresponding to each layer can be independently conducted, and the recording or reproducing of the information can be appropriately conducted on each of

information recording layers of the multi-layer type optical information recording medium.

In an optical pick-up apparatus described in (7), because the selection means changes the wavelength of the light source corresponding to each of the laminated information recording layers for the information to be recorded or reproduced, the light converging optical system to irradiate the light onto each of the information recording layers or the detection optical system of the light reflected from that can be commonly used, and although the apparatus is a structure which is simple, and whose space saving can be intended, the appropriate and quick recording or reproducing of the information can be conducted.

In an optical pick-up apparatus described in (8), because the selection means is provided with at least one optical element to change the divergence degree or convergence degree of the incident light into the final optical element corresponding to each of laminated information recording layers to record or reproduce the information on the light source side of the final optical element, when the recording or reproducing of the information is conducted on each of information recording layers, the degree of freedom in the optical design work such as the

aberration correction can be expanded. As an example of the optical element to change the divergence degree or convergence degree of the incident light into the final optical element, it includes a beam expander, coupling lens, or refractive index changing liquid crystal plate, but it is not limited to these elements.

In an optical pick-up apparatus described in (9), the optical element to change the divergence degree or convergence degree of the incident light into the final optical element has a positive lens group having the positive refractive power and a negative lens group having the negative refractive power, and at least one lens group is displaceable movable element, and the aberration correction can be arbitrarily conducted when the recording or reproducing of the information is conducted onto each of information recording layers.

In an optical pick-up apparatus described in (10), the optical element to change the divergence degree or convergence degree of the incident light into the final optical element is formed of one positive lens, and one negative lens, and because at least one of them is a displaceable and movable element, the aberration correction can be arbitrarily conducted when the recording or

reproducing of the information is conducted onto each of information recording layers.

In an optical pick-up apparatus described in (11), the information recording medium includes the first recording layer and second recording layer in the order of nearer distance from the final optical element, and in a case where the recording or reproducing is conducted onto the first recording layer, because the interval between the negative lens group and the positive lens group is increased more than a case where the recording or reproducing of the information is conducted onto the second recording layer, it can cope with a fact that it is necessary that the divergent angle of the incident light into the second recording layer is increased more than the incident light into the first recording layer.

In an optical pick-up apparatus described in (12), the optical element to change the divergence degree or convergence degree of the incident light into the final optical element corrects the spherical aberration or the axial chromatic aberration which hinders the recording or reproducing of the information, in the information recording layer to record or reproduce. Because the optical element to change the divergence degree or convergence degree of the

incident light into the final optical element not only change the information recording layer to record or reproduce the information, but also charges the change of the spherical aberration generated in the final optical element on the optical recording surface of the objective layer, and correction of the axial chromatic aberration, it is not necessary that another optical element to correct these aberrations is used, and the compactness of the optical system and the cost reduction thereof can be intended.

In an optical pick-up apparatus described in (13), the optical element to correct the variation of the spherical aberration and the axial chromatic aberration satisfies the following expression.

$$vdP > vdN \quad (1)$$

Where vdP : the average of Abbe's number of d-line of total positive lens including the positive lens (group),

vdN : the average of Abbe's number of d-line of total negative lens including the negative lens (group).

The above expression (1) shows the condition relating to the correction of axial chromatic aberration. Due to the minute variation of the oscillation wavelength of the light source or the temperature and humidity change, in the case

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$$vdN < 35 \quad (3)$$

When the difference between Abbe's numbers of the positive lens and the negative lens is increased, because the chromatic aberration of the reversal polarity to the final optical element can be generated larger, the axial chromatic aberration of the optical information recording and reproducing optical system can be corrected better.

In an optical pick-up apparatus described in (15), because the optical element to vary the divergence degree or convergence degree of the incident light to the final optical element can change the refractive index distribution, the recording or reproducing of the information can be conducted more adequately onto each of information recording layers. Herein, as the element which can change the refractive index, the refractive index change liquid crystal plate is so referred, but it is not limited to this.

In an optical pick-up apparatus described in (16), because at least one optical element which structures the light converging optical system, has at least one aspherical optical surface, by using such the aspherical optical surface, the spherical aberration generated in the optical system can be corrected.

In an optical pick-up apparatus described in (17), at least one optical element which structures the light converging optical system, is provided with the diffraction surface having the ring band-like diffraction structure, and because, by using such the diffraction surface, the axial chromatic aberration can be effectively corrected, it is not necessary that the optical element for the axial chromatic aberration correction is newly provided, and the low cost and space saving is possible. In this connection, for the optical element having the diffraction surface, in the case where the optical system is structured by a plurality of lenses, one lens is included, and particularly, when the optical system is structured by the positive lens or negative lens, it includes one of them. Further, it also includes the optical element which is separately provided other than these lenses.

In an optical pick-up apparatus described in (18), because at least one optical system constituting the light converging optical system is formed of a material whose specific gravity is not larger than 2.0, thereby, the weight reduction can be intended, and the burden onto the displacing apparatus such as the focusing apparatus can be lightened.

In an optical pick-up apparatus described in (19), because at least one optical element constituting the light converging optical system is formed of a plastic material, the weight reduction can be attained, and while lightening the burden onto the displacing apparatus such as the focusing apparatus, the processing such as the formation of the diffraction structure or aspheric surface can be easily conducted.

In an optical pick-up apparatus described in (20), because at least one optical element constituting the light converging optical system is formed of a material whose saturation water absorption is not larger than 0.5 %, the deterioration of the performance at the time of humidity change can be suppressed.

In an optical pick-up apparatus described in (21), because at least one optical element constituting the light converging optical system is formed of a material whose internal transmissivity is not smaller than 85 % at the thickness of 3 mm to the light of the oscillation wavelength of the light source, the using efficiency of the incident light can be increased.

In an optical pick-up apparatus described in (22), because the light converging optical system has at least 2

apertures to regulate the image side numerical aperture in a plurality of information recording layers of the optical information recording medium, it can change the aperture so as to regulate the information recording light for each of information layers to be recorded or reproduced, and the image formation at a predetermined image side numerical aperture (NA) can be conducted in each of information recording layers.

In an optical pick-up apparatus described in (23), at least one of the apertures is placed between the final optical element and the information recording medium. For example, when the final optical element is a catadioptric, the final surface can be divided into the mirror surface portion and the transmission portion to transmit the converging light. In such the case, when the transmission portion is made a minute opening and simultaneously the role of the aperture is made to be performed, the using efficiency of the incident light can be increased, and the low cost, size reduction, and weight reduction can be intended.

In an optical pick-up apparatus described in (24), because at least one optical element of the optical system is formed by etching, the minute optical element can be accurately molded.

An optical pick-up apparatus described in (25) has the light source, and the light converging optical system to light converge the luminous flux emitted from the light source onto any one information recording layer of the optical information recording medium having a laminated plurality of information recording layers, and in the optical pick-up apparatus by which the recording and/or reproducing of the information is conducted onto the optical information recording medium, the light converging optical system has the final optical element opposite to the optical information recording medium, spacing a smaller interval than the wavelength of the light source, and when the light converging optical system light converges the luminous flux whose image side numerical aperture is not smaller than 1.0, because the recording or reproducing of the information is conducted onto the information recording layer, the high density optical information recording or reproducing can be conducted onto the optical information recording medium, in the same manner as in the optical pick-up apparatus described in (1).

Further, because the air layer can be provided between the optical information recording medium and the final optical element, the optical information recording medium can be made, for example, to a circular rotating disk such as a CD,

and the recording and/or reproducing of the information can be conducted at the higher speed, and the optical information recording medium can be made to a removable one with excellent handling.

An optical pick-up apparatus described in (26) is characterized in that the light converging optical system has the final optical element opposed to the optical information recording medium, and the final optical surface of the final optical element is approximate to the surface of the optical information recording medium spacing the distance not larger than one fourth of the wavelength of the light source. The effect of such the invention is the same as the invention described in (3).

An optical pick-up apparatus described in (27) is characterized in that the light converging optical systems are provided plural numbers, and each of the light converging optical systems is used for recording or reproducing of the information onto the respectively different information recording layers. The effect of such the invention is the same as the invention described in (4).

An optical pick-up apparatus described in (28) is characterized in that it has the selection means to select the information recording layers to be recorded or

reproduced, and the information is recorded or reproduced onto the information recording layers selected by the selection means. The effect of such the invention is the same as the invention described in (5).

An optical pick-up apparatus described in (29) is characterized in that the light converging optical system has at least 2 final optical elements, and each final optical element is used for the recording or reproducing of the information onto the respectively different information recording layers, and when the selection means selects any one of the plurality of final optical elements, the recording or reproducing of the information is conducted onto the information recording layer corresponding to the selected final optical element. The effect of such the invention is the same as the invention described in (6).

An optical pick-up apparatus described in (30) is characterized in that the selection means changes the wavelength of the light source corresponding to each of laminated information recording layers for the information to be recorded or reproduced. The effect of such the invention is the same as the invention described in (7).

An optical pick-up apparatus described in (31) is characterized in that the selection means provides at least

one optical element by which the divergence degree or convergence degree of the incident light into the final optical element is varied corresponding to each of laminated information recording layers for the information to be recorded or reproduced, on the light source side of the final optical element. The effect of such the invention is the same as the invention described in (8).

An optical pick-up apparatus described in (32) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element has the positive lens group having the positive refractive power and the negative lens group having the negative refractive power, and at least one lens group of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (9).

An optical pick-up apparatus described in (33) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element is composed of a positive lens and a negative lens, and at least one lens of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (10).

An optical pick-up apparatus described in (34) is characterized in that the information recording medium includes the first recording layer and the second recording layer in the order of the distance nearer to the final optical element, and when the recording or reproducing is conducted onto the first recording layer, the distance between the negative lens group and the positive lens group or the distance between the negative lens and the positive lens is more increased than the case where the recording or reproducing of the information is conducted onto the second recording layer. The effect of such the invention is the same as the invention described in (11).

An optical pick-up apparatus described in (35) is characterized in that the optical element to vary the divergent degree or the convergent degree of the incident light into the final optical element corrects the spherical aberration or axial chromatic aberration which hinders the recording or reproducing of the information, in the information recording layer to be recorded or reproduced. The effect of such the invention is the same as the invention described in (12).

An optical pick-up apparatus described in (36) is characterized in that the optical element to correct the

variation of the spherical aberration and the axial chromatic aberration satisfy the following expression.

$$vdP > vdN \quad (1)$$

Where, vdP : the average of Abbe's number of d line of the all positive lenses including the positive lens (group), and vdN : the average of Abbe's number of d line of the all negative lenses including the negative lens (group). The effect of such the invention is the same as the invention described in (13).

An optical pick-up apparatus described in (37) is characterized in that the vdP and the vdN satisfy the following expression.

$$vdP > 55 \quad (2)$$

$$vdN < 35 \quad (3)$$

The effect of such the invention is the same as the invention described in (14).

An optical pick-up apparatus described in (38) is characterized in that the optical element to vary the divergent degree or convergent degree of the incident light into the final optical element can change the refractive index. The effect of such the invention is the same as the invention described in (15).

An optical pick-up apparatus described in (39) is characterized in that at least one optical element constituting the light converging optical system has at least one aspherical optical surface. The effect of such the invention is the same as the invention described in (16).

An optical pick-up apparatus described in (40) is characterized in that at least one optical element constituting the light converging optical system has the diffraction surface having the ring band-like diffraction structure. The effect of such the invention is the same as the invention described in (17).

An optical pick-up apparatus described in (41) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose specific gravity is not larger than 2.0. The effect of such the invention is the same as the invention described in (18).

An optical pick-up apparatus described in (42) is characterized in that at least one optical element constituting the light converging optical system is formed of the plastic material. The effect of such the invention is the same as the invention described in (19).

An optical pick-up apparatus described in (43) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose saturation water absorption is not larger than 0.5 %. The effect of such the invention is the same as the invention described in (20).

An optical pick-up apparatus described in (44) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose internal transmissivity is not smaller than 85 % in the thickness of 3 mm to the light of the oscillation wavelength of the light source. The effect of such the invention is the same as the invention described in (21).

An optical pick-up apparatus described in (45) is characterized in that the light converging optical system has at least 2 apertures to regulate the image side numerical aperture in a plurality of information recording layers of the optical information recording medium. The effect of such the invention is the same as the invention described in (22).

An optical pick-up apparatus described in (46) is characterized in that at least one of the apertures is positioned between the final optical element and the optical

information recording medium. The effect of such the invention is the same as the invention described in (23).

An optical pick-up apparatus described in (47) is characterized in that at least one of optical element of the light converging optical system is formed by the etching. The effect of such the invention is the same as the invention described in (24).

In an optical pick-up apparatus described in (48) which has a light source, and a light converging optical system to converge the light onto any one information recording layer of the optical information recording medium having a laminated plurality of information recording layers, and in which the recording and/or reproducing of the information is conducted onto the optical information recording medium, the optical pick-up apparatus is characterized in that the optical information recording medium has a transparent substrate whose thickness is larger than the wavelength of the light source, and the light converging optical system has a final optical element opposite to the optical information recording medium spacing the distance smaller than the wavelength of the light source, and when the light converging optical system converges the luminous flux whose image side numerical aperture is larger than 1.0 onto the information

recording layer through the transparent substrate, the recording or reproducing of the information is conducted onto the information recording layer.

One problem in the case where the near field effect is used, is that it is necessary that the distance between the final optical element and the optical information recording medium is set smaller than the wavelength of the using wavelength. However, in the case of the removable recording medium, considering the influence of flaw when the user handles it, or dust, it is common that the protective layer is provided on the information recording surface. The thickness of the protective layer is, in many cases, more than the wavelength of the light source used.

Therefore, in the present invention, using the near field effect of wide sense, it is considered that the recording or reproducing is conducted. When more specifically described, as described above, the evanescent light has the characteristic that it exponential functionally attenuates as it is separated from the final optical element, and when the transparent substrate (TP in Fig. 1) is placed in its light path, the evanescent light incident to that place, becomes again the propagation light, and has the characteristic that it propagates in the transparent

substrate as the normal light. It is called the near field effect in the wide sense. In the present invention, using such the characteristic, when the evanescent light emitted from the final optical element is received by the transparent substrate and made to a propagation light, the recording or reproducing of the information can be conducted also onto the information recording layer which is remote from the final optical surface of the final optical element more than the wavelength of the light source. In this connection, in the optical information recording medium, in many cases, the transparent protective layer covering the information recording surface is provided, and such the protective layer can perform the function as the transparent substrate of the present invention. Accordingly, the interval Δ between the final optical element and the surface of the protective layer of the optical information recording medium may be smaller than the wavelength of the information recording light. Herein, when the layer can transmit the light, the transparent substrate may not be colored or plate-like one.

An optical pick-up apparatus described in (49) is characterized in that the final optical surface of the final optical element is approximate to the surface of the optical information recording medium spacing with the distance

smaller than one fourth of the wavelength of the light source. The effect of such the invention is the same as the invention described in (3).

An optical pick-up apparatus described in (50) is characterized in that a plurality of light converging optical systems are provided, and each of light converging optical systems is used for the recording or reproducing of the information onto the respectively different information recording layers. The effect of such the invention is the same as the invention described in (4).

An optical pick-up apparatus described in (51) is characterized in that the apparatus has a selection means for selecting the information recording layer to be recorded or reproduced from the laminated plurality of plurality of information recording layers, and the recording or reproducing of the information is conducted onto the information recording layer selected by the selection means. The effect of such the invention is the same as the invention described in (5).

An optical pick-up apparatus described in (52) is characterized in that the light converging optical system has at least 2 final optical elements, and each of final optical elements is used for the recording or reproducing of the

information onto the respectively different information recording layers, and when the selection means selects any one of final optical elements, the recording or reproducing of the information is conducted onto the information recording layer corresponding to the selected final optical element. The effect of such the invention is the same as the invention described in (6).

An optical pick-up apparatus described in (53) is characterized in that the selection means changes the wavelength of the light source corresponding to each of laminated information recording layers for the information to be recorded and reproduced. The effect of such the invention is the same as the invention described in (7).

An optical pick-up apparatus described in (54) is characterized in that at least one optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, corresponding to each of laminated information recording layers for the information to be recorded and reproduced, is provided on the light source side of the final optical element. The effect of such the invention is the same as the invention described in (8).

An optical pick-up apparatus described in (55) is characterized in that the optical element to vary the

divergence degree or convergence degree of the incident light into the final optical element has the positive lens group having the positive refractive power and the negative lens group having the negative refractive power, and at least one lens group of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (9).

An optical pick-up apparatus described in (56) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element is composed of one positive lens and one negative lens, and at least one of them is is a displaceable movable element. The effect of such the invention is the same as the invention described in (10).

An optical pick-up apparatus described in (57) is characterized in that the information recording medium includes the first recording layer and the second recording layer in the order of the distance nearer to the final optical element, and when the recording or reproducing of the information is conducted onto the first recording layer, the interval between the negative lens group and the positive lens group or the distance between the positive lens and the negative lens is more increased than the case where the

recording or reproducing of the information is conducted onto the second recording layer. The effect of such the invention is the same as the invention described in (11).

An optical pick-up apparatus described in (58) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element corrects the spherical aberration or the axial chromatic aberration which hinders the recording or reproducing of the information, in the information recording layer to be recorded or reproduced. The effect of such the invention is the same as the invention described in (12).

An optical pick-up apparatus described in (59) is characterized in that the optical element to correct the variation of the spherical aberration and the axial chromatic aberration satisfies the following expression.

$$vdP > vdN \quad (1)$$

where, vdP : the average of Abbe's number of d line of all positive lens including the positive lens (group), vdN : the average of Abbe's number of d line of all negative lens including the negative lens (group). The effect of such the invention is the same as the invention described in (13).

An optical pick-up apparatus described in (60) is characterized in that the value vdP and the value vdN satisfy the following expressions.

$$vdP > 55 \quad (2)$$

$$vdN < 35 \quad (3)$$

The effect of such the invention is the same as the invention described in (14).

An optical pick-up apparatus described in (61) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element can changes the refractive index distribution. The effect of such the invention is the same as the invention described in (15).

An optical pick-up apparatus described in (62) is characterized in that at least one optical element constituting the light converging optical system has at least one aspherical optical surface. The effect of such the invention is the same as the invention described in (16).

An optical pick-up apparatus described in (63) is characterized in that at least one optical element constituting the light converging optical system has a diffraction surface having the ring band-like diffraction

structure. The effect of such the invention is the same as the invention described in (17).

An optical pick-up apparatus described in (64) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose specific gravity is not larger than 2.0. The effect of such the invention is the same as the invention described in (18).

An optical pick-up apparatus described in (65) is characterized in that at least one optical element constituting the light converging optical system is formed of a plastic material. The effect of such the invention is the same as the invention described in (19).

An optical pick-up apparatus described in (66) is characterized in that at least one optical element constituting the light converging optical system is formed of a material whose saturation water absorption is not larger than 0.5 %. The effect of such the invention is the same as the invention described in (20).

An optical pick-up apparatus described in (67) is characterized in that at least one optical element constituting the light converging optical system is formed of a material whose internal transmissivity at the thickness of

3 mm to the light of oscillation wavelength of the light source is not smaller than 85 %. The effect of such the invention is the same as the invention described in (21).

An optical pick-up apparatus described in (68) is characterized in that the light converging optical system has at least 2 diaphragms to regulate the image side numerical aperture in a plurality of information recording layers of the optical information recording medium. The effect of such the invention is the same as the invention described in (22).

An optical pick-up apparatus described in (69) is characterized in that at least one of the diaphragms is positioned between the final optical element and the optical information recording medium. The effect of such the invention is the same as the invention described in (23).

An optical pick-up apparatus described in (70) is characterized in that at least one optical element of the light converging optical system is formed by etching. The effect of such the invention is the same as the invention described in (24).

In an optical pick-up apparatus described in (71) which has the light source and the light converging optical system to light converge the luminous flux emitted from the light source onto any one of information recording layers of the

optical information recording medium having a laminated plurality of information recording layers, and by which the recording and/or reproducing of the information is conducted onto the optical information recording medium, because the optical element changes the information recording layer for the information to be recorded or reproduced is provided between the light source and the final optical element of the light converging optical system, the information recording light can be adequately irradiated onto each of information recording layers of the multi-layer type optical information recording medium by the simple and low cost structure.

An optical pick-up apparatus described in (72) is characterized in that the optical element to change the information recording layers onto which the information is to be recorded or reproduced changes the divergence degree or convergence degree of the incident light into the final optical element. The effect of such the invention is the same as the invention described in (8).

An optical pick-up apparatus described in (73) is characterized in that the optical element by which the divergence degree or convergence degree of the incident light into the final optical element is changed, has the positive lens group having the positive refractive power and the

negative lens group having the negative refractive power, and at least one lens group of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (9).

An optical pick-up apparatus described in (74) is characterized in that the optical element to vary the divergent degree or convergence degree of the incident light into the final optical element is composed of one positive lens and one negative lens, and at least one of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (10).

An optical pick-up apparatus described in (75) is characterized in that the information recording medium includes the first recording layer and the second recording layer in the order of the distance nearer from the final optical element, and when the recording or reproducing is conducted onto the first recording layer, the interval between the negative lens group and the positive lens group or the interval between the negative lens and the positive lens is more increased than the case where the recording or reproducing of the information is conducted onto the second recording layer. The effect of such the invention is the same as the invention described in (11).

An optical pick-up apparatus described in (76) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element corrects the spherical aberration or axial chromatic aberration which hinders the recording or reproducing of the information in the information recording layer onto which the recording or reproducing is to be conducted. The effect of such the invention is the same as the invention described in (12).

An optical pick-up apparatus described in (77) is characterized in that the optical element which corrects the spherical aberration and axial chromatic aberration satisfies the following expression.

$$vdP > vdN \quad (1)$$

Where, vdP : the average of Abbe's number of the d line of all positive lenses including the positive lens (group),
 vdN : the average of Abbe's number of the d line of all negative lenses including the negative lens (group). The effect of such the invention is the same as the invention described in (13).

An optical pick-up apparatus described in (78) is characterized in that the vdP and the vdN satisfy the following expressions.

$$vdP > 55 \quad (2)$$

$$vdN < 35 \quad (3)$$

The effect of such the invention is the same as the invention described in (14).

An optical pick-up apparatus described in (79) is characterized in that the optical element to vary the divergence degree and the convergence degree of the incident light into the final optical element can change the refractive index distribution. The effect of such the invention is the same as the invention described in (15).

An optical pick-up apparatus described in (80) is characterized in that at least one optical element constituting the light converging optical system has at least one aspherical optical surface. The effect of such the invention is the same as the invention described in (16).

An optical pick-up apparatus described in (81) is characterized in that at least one optical element constituting the light converging optical system has the diffraction surface having the ring band-like diffraction

structure. The effect of such the invention is the same as the invention described in (17).

An optical pick-up apparatus described in (82) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose specific gravity is not larger than 2.0. The effect of such the invention is the same as the invention described in (18).

An optical pick-up apparatus described in (83) is characterized in that at least one optical element constituting the light converging optical system is formed of the plastic material. The effect of such the invention is the same as the invention described in (19).

An optical pick-up apparatus described in (84) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose saturation water absorption is not larger than 0.5 %. The effect of such the invention is the same as the invention described in (20).

An optical pick-up apparatus described in (85) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose internal transmissivity at the 3 mm

thickness to the light of oscillation wavelength of the light source is not smaller than 85 %. The effect of such the invention is the same as the invention described in (21).

An optical pick-up apparatus described in (86) is characterized in that the light converging optical system has at least 2 diaphragms to regulate the image side numerical aperture in a plurality of information recording layers of the optical information recording medium. The effect of such the invention is the same as the invention described in (22).

An optical pick-up apparatus described in (87) is characterized in that at least one diaphragm of the diaphragms is positioned between the final optical element and the optical information recording medium. The effect of such the invention is the same as the invention described in (23).

An optical pick-up apparatus described in (88) is characterized in that at least one optical element of the light converging optical system is formed by etching. The effect of such the invention is the same as the invention described in (24).

In a light converging optical system of an optical pick-up apparatus described in (89) which has the light source and the light converging optical system to light

converge the luminous flux emitted from the light source onto any one of information recording layers of the optical information recording medium having a laminated plurality of information recording layers, and by which the recording and/or reproducing of the information is conducted onto the optical information recording medium, the light converging optical system is characterized in that, when the light converging optical system light converges the luminous flux whose image side numerical aperture is not smaller than 1.0, onto the information recording layer, the recording or reproducing of the information is conducted onto the information recording layer. The effect of such the invention is the same as the invention described in (1).

A light converging optical system of an optical pick-up apparatus described in (90) is characterized in that it has the final optical element opposite to the optical information recording medium, and the final optical surface of the final optical element is in contact with the surface of the optical information recording medium. The effect of such the invention is the same as the invention described in (2).

A light converging optical system of an optical pick-up apparatus described in (91) is characterized in that it has the final optical element opposite to the optical information

recording medium, and the final optical surface of the final optical element is approximate to the surface of the optical information recording medium spacing the interval not larger than one fourth of the wavelength of the light source. The effect of such the invention is the same as the invention described in (3).

A light converging optical system of an optical pick-up apparatus described in (92) is characterized in that a plurality of light converging optical systems are provided, and each of light converging systems is used for the recording or reproducing of the information onto the respectively different information recording layers. The effect of such the invention is the same as the invention described in (4).

A light converging optical system of an optical pick-up apparatus described in (93) is characterized in that it has a selection means for selecting the information recording layer onto which the recording or reproducing is to be conducted, from a laminated plurality of information recording layers, and the recording or reproducing of the information is conducted onto the information recording layer selected by the selection means. The effect of such the invention is the same as the invention described in (5).

A light converging optical system of an optical pick-up apparatus described in (94) is characterized in that the light converging optical system has at least 2 final optical elements, and each of the final optical elements is used for the recording or reproducing of the information onto the respectively different information recording layers, and when the selection means selects any one of the plurality of final optical elements, the recording or reproducing of the information is conducted onto the information recording layer corresponding to the selected final optical element. The effect of such the invention is the same as the invention described in (6).

A light converging optical system of an optical pick-up apparatus described in (95) is characterized in that the selection means changes the wavelength of the light source corresponding to each of laminated information recording layers onto which the recording or reproducing of the information is to be conducted. The effect of such the invention is the same as the invention described in (7).

A light converging optical system of an optical pick-up apparatus described in (96) is characterized in that the selection means provides at least one optical element to vary the divergence degree or convergence degree of the incident

light into the final optical element on the light source side of the final optical element, corresponding to each of laminated information recording layers onto which the recording or reproducing of the information is to be conducted. The effect of such the invention is the same as the invention described in (8).

A light converging optical system of an optical pick-up apparatus described in (97) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, has the positive lens group having the positive refractive power and the negative lens group having the negative refractive power, and at least one lens group of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (9).

A light converging optical system of an optical pick-up apparatus described in (98) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, is composed of one positive lens and one negative lens, and at least one of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (10).

A light converging optical system of an optical pick-up apparatus described in (99) is characterized in that the information recording medium includes the first recording layer and the second recording layer in the order of the distance nearer from the final optical element, and when the recording or reproducing is conducted onto the first recording layer, the interval between the negative lens group and the positive lens group or the interval between the negative lens and the positive lens is more increased than the case where the recording or reproducing of the information is conducted onto the second recording layer. The effect of such the invention is the same as the invention described in (11).

A light converging optical system of an optical pick-up apparatus described in (100) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, corrects the spherical aberration or axial chromatic aberration which hinders the recording or reproducing of the information, in the information recording layer onto which the recording or reproducing is to be conducted. The effect of such the invention is the same as the invention described in (12).

A light converging optical system of an optical pick-up apparatus described in (101) is characterized in that the optical element to correct the variation of the spherical aberration and the axial chromatic aberration satisfies the following expression.

$$vdP > vdN \quad (1)$$

Where, vdP : the average of Abbe's number of the d line of all positive lenses including the positive lens (group),
 vdN : the average of Abbe's number of the d line of all negative lenses including the negative lens (group). The effect of such the invention is the same as the invention described in (13).

A light converging optical system of an optical pick-up apparatus described in (102) is characterized in that the vdP and the vdN satisfy the following expressions.

$$vdP > 55 \quad (2)$$

$$vdN < 35 \quad (3)$$

The effect of such the invention is the same as the invention described in (14).

A light converging optical system of an optical pick-up apparatus described in (103) is characterized in that the optical element to vary the divergence degree or convergence

degree of the incident light into the final optical element can change the refractive index distribution. The effect of such the invention is the same as the invention described in (15).

A light converging optical system of an optical pick-up apparatus described in (104) is characterized in that at least one optical element constituting the light converging optical system has at least one aspherical optical surface. The effect of such the invention is the same as the invention described in (16).

A light converging optical system of an optical pick-up apparatus described in (105) is characterized in that at least one optical element constituting the light converging optical system has a diffraction surface having a ring band-like diffraction structure. The effect of such the invention is the same as the invention described in (17).

A light converging optical system of an optical pick-up apparatus described in (106) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose specific gravity is not larger than 2.0. The effect of such the invention is the same as the invention described in (18).

A light converging optical system of an optical pick-up apparatus described in (107) is characterized in that at least one optical element constituting the light converging optical system is formed of the plastic material. The effect of such the invention is the same as the invention described in (19).

A light converging optical system of an optical pick-up apparatus described in (108) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose saturation water absorption is not larger than 0.5 %. The effect of such the invention is the same as the invention described in (20).

A light converging optical system of an optical pick-up apparatus described in (109) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose internal transmissivity at the 3 mm thickness to the light of the oscillation wavelength of the light source is not smaller than 85 %. The effect of such the invention is the same as the invention described in (21).

A light converging optical system of an optical pick-up apparatus described in (110) is characterized in that the

light converging optical system has at least 2 diaphragms to regulate the image side numerical aperture in a plurality of information recording layers of the optical information recording medium. The effect of such the invention is the same as the invention described in (22).

A light converging optical system of an optical pick-up apparatus described in (111) is characterized in that at least one of diaphragms is positioned between the final optical element and the optical information recording medium. The effect of such the invention is the same as the invention described in (23).

A light converging optical system of an optical pick-up apparatus described in (112) is characterized in that at least one optical element of the light converging optical system is formed by etching. The effect of such the invention is the same as the invention described in (24).

In a light converging optical system of an optical pick-up apparatus described in (113) which has the light source and the light converging optical system to light converge the luminous flux emitted from the light source onto any one of information recording layers of the optical information recording medium having a laminated plurality of information recording layers, and by which the recording

and/or reproducing of the information is conducted onto the optical information recording medium, the light converging optical system is characterized in that, it has the final optical element opposite to the optical information recording medium spacing the distance not larger than the wavelength of the light source, and when the light converging optical system light converges the luminous flux whose image side numerical aperture is not smaller than 1.0, onto the information recording layer, the recording or reproducing of the information is conducted onto the information recording layer. The effect of such the invention is the same as the invention described in (25).

A light converging optical system of an optical pick-up apparatus described in (114) is characterized in that it has the final optical element opposite to the optical information recording medium, and the final optical surface of the final optical element is approximate to the surface of the optical information recording medium spacing the distance not larger than one fourth of the wavelength of the light source. The effect of such the invention is the same as the invention described in (3).

A light converging optical system of an optical pick-up apparatus described in (115) is characterized in that a

plurality of light converging elements are provided, and each of light converging elements is used for the recording or reproducing of the information onto the respectively different information recording layers. The effect of such the invention is the same as the invention described in (4).

A light converging optical system of an optical pick-up apparatus described in (116) is characterized in that it has a selection means for selecting the information recording layer onto which the recording or reproducing is to be conducted, from the laminated plurality of information recording layers, and the recording or reproducing of the information is conducted onto the information recording layer selected by the selection means. The effect of such the invention is the same as the invention described in (5).

A light converging optical system of an optical pick-up apparatus described in (117) is characterized in that it has at least 2 final optical element and each of the final optical elements is used for the recording or reproducing of the information onto the respectively different information recording layers, and when the selection means selects any one of the plurality of final optical elements, the recording or reproducing of the information is conducted onto the information recording layer corresponding to the selected

final optical element. The effect of such the invention is the same as the invention described in (6).

A light converging optical system of an optical pick-up apparatus described in (118) is characterized in that the selection means changes the wavelength of the light source corresponding to each of information recording layers onto which the recording and reproducing of the information is to be conducted. The effect of such the invention is the same as the invention described in (7).

A light converging optical system of an optical pick-up apparatus described in (119) is characterized in that the selection means is provided with, corresponding to each of laminated information recording layers onto which the recording or reproducing of the information to be conducted, at least one optical element to vary the divergence degree or convergence degree of the incident light into the final optical element on the light source side of the final optical element. The effect of such the invention is the same as the invention described in (8).

A light converging optical system of an optical pick-up apparatus described in (120) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element,

has the positive lens group having the positive refractive power and the negative lens group having the negative refractive power, and at least one lens group of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (9).

A light converging optical system of an optical pick-up apparatus described in (121) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, is composed of one positive lens and one negative lens, and at least one of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (10).

A light converging optical system of an optical pick-up apparatus described in (122) is characterized in that the information recording medium includes the first recording layer and the second recording layer in the order of the distance nearer from the final optical element, and when the recording or reproducing is conducted onto the first recording layer, the interval between the negative lens group and the positive lens group or the interval between the negative lens and the positive lens is more increased than the case where the recording or reproducing of the

information is conducted onto the second recording layer. The effect of such the invention is the same as the invention described in (11).

A light converging optical system of an optical pick-up apparatus described in (123) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, corrects the spherical aberration or axial chromatic aberration which hinders the recording or reproducing of the information, in the information recording layer onto which the recording or reproducing is to be conducted. The effect of such the invention is the same as the invention described in (12).

A light converging optical system of an optical pick-up apparatus described in (124) is characterized in that the optical element to correct the variation of the spherical aberration and the axial chromatic aberration satisfies the following expression.

$$vdP > vdN \quad (1)$$

Where, vdP : the average of Abbe's number of the d line of all positive lenses including the positive lens (group),
 vdN : the average of Abbe's number of the d line of all

negative lenses including the negative lens (group). The effect of such the invention is the same as the invention described in (13).

A light converging optical system of an optical pick-up apparatus described in (125) is characterized in that the vdP and the vdN satisfy the following expressions.

$$vdP > 55 \quad (2)$$

$$vdN < 35 \quad (3)$$

The effect of such the invention is the same as the invention described in (14).

A light converging optical system of an optical pick-up apparatus described in (126) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element can change the refractive index distribution. The effect of such the invention is the same as the invention described in (15).

A light converging optical system of an optical pick-up apparatus described in (127) is characterized in that at least one optical element constituting the light converging optical system has at least one aspherical optical surface.

The effect of such the invention is the same as the invention described in (16).

A light converging optical system of an optical pick-up apparatus described in (128) is characterized in that at least one optical element constituting the light converging optical system has a diffraction surface having a ring band-like diffraction structure. The effect of such the invention is the same as the invention described in (17).

A light converging optical system of an optical pick-up apparatus described in (129) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose specific gravity is not larger than 2.0. The effect of such the invention is the same as the invention described in (18).

A light converging optical system of an optical pick-up apparatus described in (130) is characterized in that at least one optical element constituting the light converging optical system is formed of the plastic material. The effect of such the invention is the same as the invention described in (19).

A light converging optical system of an optical pick-up apparatus described in (131) is characterized in that at least one optical element constituting the light converging

optical system is formed of the material whose saturation water absorption is not larger than 0.5 %. The effect of such the invention is the same as the invention described in (20).

A light converging optical system of an optical pick-up apparatus described in (132) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose internal transmissivity at the 3 mm thickness to the light of the oscillation wavelength of the light source is not smaller than 85 %. The effect of such the invention is the same as the invention described in (21).

A light converging optical system of an optical pick-up apparatus described in (133) is characterized in that the light converging optical system has at least 2 diaphragms to regulate the image side numerical aperture in a plurality of information recording layers of the optical information recording medium. The effect of such the invention is the same as the invention described in (22).

A light converging optical system of an optical pick-up apparatus described in (134) is characterized in that at least one of diaphragms is positioned between the final optical element and the optical information recording medium.

The effect of such the invention is the same as the invention described in (23).

A light converging optical system of an optical pick-up apparatus described in (135) is characterized in that at least one optical element of the light converging optical system is formed by etching. The effect of such the invention is the same as the invention described in (24).

In a light converging optical system of an optical pick-up apparatus described in (136) which has the light source and the light converging optical system to light converge the luminous flux emitted from the light source onto any one of information recording layers of the optical information recording medium having a laminated plurality of information recording layers, and by which the recording and/or reproducing of the information is conducted onto the optical information recording medium, the light converging optical system is characterized in that the optical information recording medium has a transparent substrate whose thickness is not smaller than the wavelength of the light source on the information recording layer nearest to the light converging optical system side, and the light converging optical system has the final optical element opposite to the optical information recording medium spacing

the distance not larger than the wavelength of the light source, and when the light converging optical system light converges the luminous flux whose image side numerical aperture is not smaller than 1.0, onto the information recording layer through the transparent substrate, the recording or reproducing of the information is conducted onto the information recording layer. The effect of such the invention is the same as the invention described in (48).

A light converging optical system of an optical pick-up apparatus described in (137) is characterized in that the final optical surface of final optical element is approximate to the surface of the optical information recording medium spacing the interval not larger than one fourth of the wavelength of the light source. The effect of such the invention is the same as the invention described in (3).

A light converging optical system of an optical pick-up apparatus described in (138) is characterized in that a plurality of light converging optical systems are provided, and each of light converging optical systems is used for the recording or reproducing of the information onto the respectively different information recording layers. The effect of such the invention is the same as the invention described in (4).

A light converging optical system of an optical pick-up apparatus described in (139) is characterized in that it has a selection means for selecting the information recording layer onto which the recording or reproducing is to be conducted, from the laminated plurality of information recording layers, and the recording or reproducing of the information is conducted onto the information recording layer selected by the selection means. The effect of such the invention is the same as the invention described in (5).

A light converging optical system of an optical pick-up apparatus described in (140) is characterized in that a plurality of light converging optical systems are provided, and each of light converging optical systems is used for the recording or reproducing of the information onto the respectively different information recording layers, and when the selection means selects any one of the plurality of final optical elements, the recording or reproducing of the information is conducted onto the information recording layer corresponding to the selected final optical element. The effect of such the invention is the same as the invention described in (6).

A light converging optical system of an optical pick-up apparatus described in (141) is characterized in that the

selection means changes the wavelength of the light source corresponding to each of laminated information recording layers onto which the recording or reproducing of the information is to be conducted. The effect of such the invention is the same as the invention described in (7).

A light converging optical system of an optical pick-up apparatus described in (142) is characterized in that the selection means provides at least one optical element to vary the divergence degree or convergence degree of the incident light into the final optical element on the light source side of the final optical element, corresponding to each of laminated information recording layers onto which the recording or reproducing of the information is to be conducted. The effect of such the invention is the same as the invention described in (8).

A light converging optical system of an optical pick-up apparatus described in (143) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, has the positive lens group having the positive refractive power and the negative lens group having the negative refractive power, and at least one lens group of them is a

displaceable movable element. The effect of such the invention is the same as the invention described in (9).

A light converging optical system of an optical pick-up apparatus described in (144) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, is composed of one positive lens and one negative lens, and at least one of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (10).

A light converging optical system of an optical pick-up apparatus described in (145) is characterized in that the information recording medium includes the first recording layer and the second recording layer in the order of the distance nearer from the final optical element, and when the recording or reproducing is conducted onto the first recording layer, the interval between the negative lens group and the positive lens group or the interval between the negative lens and the positive lens is more increased than the case where the recording or reproducing of the information is conducted onto the second recording layer. The effect of such the invention is the same as the invention described in (11).

A light converging optical system of an optical pick-up apparatus described in (146) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, corrects the spherical aberration or axial chromatic aberration which hinders the recording or reproducing of the information, in the information recording layer onto which the recording or reproducing is to be conducted. The effect of such the invention is the same as the invention described in (12).

A light converging optical system of an optical pick-up apparatus described in (147) is characterized in that the optical element to correct the variation of the spherical aberration and the axial chromatic aberration satisfies the following expression.

$$vdP > vdN \quad (1)$$

Where, vdP : the average of Abbe's number of the d line of all positive lenses including the positive lens (group),
 vdN : the average of Abbe's number of the d line of all negative lenses including the negative lens (group). The effect of such the invention is the same as the invention described in (13).

A light converging optical system of an optical pick-up apparatus described in (148) is characterized in that the vdP and the vdN satisfy the following expressions.

$$vdP > 55 \quad (2)$$

$$vdN < 35 \quad (3)$$

The effect of such the invention is the same as the invention described in (14).

A light converging optical system of an optical pick-up apparatus described in (149) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element can change the refractive index distribution. The effect of such the invention is the same as the invention described in (15).

A light converging optical system of an optical pick-up apparatus described in (150) is characterized in that at least one optical element constituting the light converging optical system has at least one aspherical optical surface. The effect of such the invention is the same as the invention described in (16).

A light converging optical system of an optical pick-up apparatus described in (151) is characterized in that at

least one optical element constituting the light converging optical system has a diffraction surface having a ring band-like diffraction structure. The effect of such the invention is the same as the invention described in (17).

A light converging optical system of an optical pick-up apparatus described in (152) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose specific gravity is not larger than 2.0. The effect of such the invention is the same as the invention described in (18).

A light converging optical system of an optical pick-up apparatus described in (153) is characterized in that at least one optical element constituting the light converging optical system is formed of the plastic material. The effect of such the invention is the same as the invention described in (19).

A light converging optical system of an optical pick-up apparatus described in (154) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose saturation water absorption is not larger than 0.5 %. The effect of such the invention is the same as the invention described in (20).

A light converging optical system of an optical pick-up apparatus described in (155) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose internal transmissivity at the 3 mm thickness to the light of the oscillation wavelength of the light source is not smaller than 85 %. The effect of such the invention is the same as the invention described in (21).

A light converging optical system of an optical pick-up apparatus described in (156) is characterized in that the light converging optical system has at least 2 diaphragms to regulate the image side numerical aperture in a plurality of information recording layers of the optical information recording medium. The effect of such the invention is the same as the invention described in (22).

A light converging optical system of an optical pick-up apparatus described in (157) is characterized in that at least one of diaphragms is positioned between the final optical element and the optical information recording medium. The effect of such the invention is the same as the invention described in (23).

A light converging optical system of an optical pick-up apparatus described in (158) is characterized in that at

least one optical element of the light converging optical system is formed by etching. The effect of such the invention is the same as the invention described in (24).

In a light converging optical system of an optical pick-up apparatus described in (159) which has the light source and the light converging optical system to light converge the luminous flux emitted from the light source onto any one of information recording layers of the optical information recording medium having a laminated plurality of information recording layers, and by which the recording and/or reproducing of the information is conducted onto the optical information recording medium, the light converging optical system is characterized in that, it is provided with the optical element to change the information recording layer onto which the recording or reproducing of the information is to be conducted, between the light source and the final optical element of the light converging optical system. The effect of such the invention is the same as the invention described in (71).

An optical pick-up apparatus described in (160) is characterized in that the optical element to change the information recording layers onto which the information is to be recorded or reproduced varies the divergence degree or

convergence degree of the incident light into the final optical element. The effect of such the invention is the same as the invention described in (8).

An optical pick-up apparatus described in (161) is characterized in that the optical element by which the divergence degree or convergence degree of the incident light into the final optical element is changed, has the positive lens group having the positive refractive power and the negative lens group having the negative refractive power, and at least one lens group of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (9).

An optical pick-up apparatus described in (162) is characterized in that the optical element to vary the divergent degree or convergence degree of the incident light into the final optical element is composed of one positive lens and one negative lens, and at least one of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (10).

An optical pick-up apparatus described in (163) is characterized in that the information recording medium includes the first recording layer and the second recording layer in the order of the distance nearer from the final

optical element, and when the recording or reproducing is conducted onto the first recording layer, the interval between the negative lens group and the positive lens group or the interval between the negative lens and the positive lens is more increased than the case where the recording or reproducing of the information is conducted onto the second recording layer. The effect of such the invention is the same as the invention described in (11).

An optical pick-up apparatus described in (164) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element corrects the spherical aberration or axial chromatic aberration which hinders the recording or reproducing of the information in the information recording layer onto which the recording or reproducing is to be conducted. The effect of such the invention is the same as the invention described in (12).

An optical pick-up apparatus described in (165) is characterized in that the optical element which corrects the spherical aberration and axial chromatic aberration satisfies the following expression.

$$vdP > vdN \quad (1)$$

Where, vdP : the average of Abbe's number of the d line of all positive lenses including the positive lens (group),
 vdN : the average of Abbe's number of the d line of all negative lenses including the negative lens (group). The effect of such the invention is the same as the invention described in (13).

An optical pick-up apparatus described in (166) is characterized in that the vdP and the vdN satisfy the following expressions.

$$vdP > 55 \quad (2)$$

$$vdN < 35 \quad (3)$$

The effect of such the invention is the same as the invention described in (14).

An optical pick-up apparatus described in (79) is characterized in that the optical element to vary the divergence degree and the convergence degree of the incident light into the final optical element can change the refractive index distribution. The effect of such the invention is the same as the invention described in (15).

An optical pick-up apparatus described in (168) is characterized in that at least one optical element constituting the light converging optical system has at least

one aspherical optical surface. The effect of such the invention is the same as the invention described in (16).

An optical pick-up apparatus described in (169) is characterized in that at least one optical element constituting the light converging optical system has the diffraction surface having the ring band-like diffraction structure. The effect of such the invention is the same as the invention described in (17).

An optical pick-up apparatus described in (170) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose specific gravity is not larger than 2.0. The effect of such the invention is the same as the invention described in (18).

An optical pick-up apparatus described in (171) is characterized in that at least one optical element constituting the light converging optical system is formed of the plastic material. The effect of such the invention is the same as the invention described in (19).

An optical pick-up apparatus described in (172) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose saturation water absorption is not larger

than 0.5 %. The effect of such the invention is the same as the invention described in (20).

An optical pick-up apparatus described in (173) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose internal transmissivity at the 3 mm thickness to the light of oscillation wavelength of the light source is not smaller than 85 %. The effect of such the invention is the same as the invention described in (21).

An optical pick-up apparatus described in (174) is characterized in that the light converging optical system has at least 2 diaphragms to regulate the image side numerical aperture in a plurality of information recording layers of the optical information recording medium. The effect of such the invention is the same as the invention described in (22).

An optical pick-up apparatus described in (175) is characterized in that at least one diaphragm of the diaphragms is positioned between the final optical element and the optical information recording medium. The effect of such the invention is the same as the invention described in (23).

An optical pick-up apparatus described in (176) is characterized in that at least one optical element of the

light converging optical system is formed by etching. The effect of such the invention is the same as the invention described in (24).

An optical information recording and reproducing method described in (177) is characterized in that, by using an optical pick-up apparatus which has the light source and the light converging optical system to light converge the luminous flux emitted from the light source onto any one of information recording layers of the optical information recording medium having a laminated plurality of information recording layers, the recording or reproducing of the information is conducted onto the information recording layer by the luminous flux whose image side numerical aperture is not smaller than 1.0, from the light converging optical system. The effect of such the invention is the same as the invention described in (1).

An optical information recording and reproducing method described in (178) is characterized in that the light converging optical system has the final optical element opposite to the optical information recording medium, and the final optical surface of the final optical element is in contact with the surface of the optical information recording

medium. The effect of such the invention is the same as the invention described in (2).

An optical information recording and reproducing method described in (179) is characterized in that the light converging optical system has the final optical element opposite to the optical information recording medium, and the final optical surface of the final optical element is approximate to the surface of the optical information recording medium spacing the interval not larger than one fourth of the wavelength of the light source. The effect of such the invention is the same as the invention described in (3).

An optical information recording and reproducing method described in (180) is characterized in that a plurality of light converging optical systems are provided, and each of light converging optical systems is used for the recording or reproducing of the information onto the respectively different information recording layers. The effect of such the invention is the same as the invention described in (4).

An optical information recording and reproducing method described in (181) is characterized in that the optical pick-up apparatus has a selection means for selecting the

information recording layer onto which the recording or reproducing is to be conducted, from a laminated plurality of information recording layers, and the recording or reproducing of the information is conducted onto the information recording layer selected by the selection means. The effect of such the invention is the same as the invention described in (5).

An optical information recording and reproducing method described in (182) is characterized in that the light converging optical system has at least 2 final optical elements, and each of the final optical elements is used for the recording or reproducing of the information onto the respectively different information recording layers, and when the selection means selects either one of the plurality of final optical elements, the recording or reproducing of the information is conducted onto the information recording layer corresponding to the selected final optical element. The effect of such the invention is the same as the invention described in (6).

An optical information recording and reproducing method described in (183) is characterized in that the selection means changes the wavelength of the light source, corresponding to each of laminated information recording

layers onto which the recording or reproducing of the information is to be conducted. The effect of such the invention is the same as the invention described in (7).

An optical information recording and reproducing method described in (184) is characterized in that the selection means provides at least one optical element to vary the divergence degree or convergence degree of the incident light into the final optical element on the light source side of the final optical element, corresponding to each of laminated information recording layers onto which the recording or reproducing of the information is to be conducted. The effect of such the invention is the same as the invention described in (8).

An optical information recording and reproducing method described in (185) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, has the positive lens group having the positive refractive power and the negative lens group having the negative refractive power, and at least one lens group of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (9).

An optical information recording and reproducing method described in (186) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, is composed of one positive lens and one negative lens, and at least one of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (10).

An optical information recording and reproducing method described in (187) is characterized in that the information recording medium includes the first recording layer and the second recording layer in the order of the distance nearer from the final optical element, and when the recording or reproducing is conducted onto the first recording layer, the interval between the negative lens group and the positive lens group or the interval between the negative lens and the positive lens is more increased than the case where the recording or reproducing of the information is conducted onto the second recording layer. The effect of such the invention is the same as the invention described in (11).

An optical information recording and reproducing method described in (188) is characterized in that the optical element to vary the divergence degree or convergence degree

of the incident light into the final optical element, corrects the spherical aberration or axial chromatic aberration which hinders the recording or reproducing of the information, in the information recording layer onto which the recording or reproducing is to be conducted. The effect of such the invention is the same as the invention described in (12).

An optical information recording and reproducing method described in (189) is characterized in that the optical element to correct the variation of the spherical aberration and the axial chromatic aberration satisfies the following expression.

$$vdP > vdN \quad (1)$$

Where, vdP : the average of Abbe's number of the d line of all positive lenses including the positive lens (group),
 vdN : the average of Abbe's number of the d line of all negative lenses including the negative lens (group). The effect of such the invention is the same as the invention described in (13).

An optical information recording and reproducing method described in (190) is characterized in that the vdP and the vdN satisfy the following expressions.

$$vdP > 55 \quad (2)$$

$$vdN < 35 \quad (3)$$

The effect of such the invention is the same as the invention described in (14).

An optical information recording and reproducing method described in (191) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element can change the refractive index distribution. The effect of such the invention is the same as the invention described in (15).

An optical information recording and reproducing method described in (192) is characterized in that at least one optical element constituting the light converging optical system has at least one aspherical optical surface. The effect of such the invention is the same as the invention described in (16).

An optical information recording and reproducing method described in (193) is characterized in that at least one optical element constituting the light converging optical system has a diffraction surface having a ring band-like diffraction structure. The effect of such the invention is the same as the invention described in (17).

An optical information recording and reproducing method described in (194) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose specific gravity is not larger than 2.0. The effect of such the invention is the same as the invention described in (18).

An optical information recording and reproducing method described in (195) is characterized in that at least one optical element constituting the light converging optical system is formed of the plastic material. The effect of such the invention is the same as the invention described in (19).

An optical information recording and reproducing method described in (196) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose saturation water absorption is not larger than 0.5 %. The effect of such the invention is the same as the invention described in (20).

An optical information recording and reproducing method described in (197) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose internal transmissivity at the 3 mm thickness to the light of the oscillation wavelength of the light source is not smaller

than 85 %. The effect of such the invention is the same as the invention described in (21).

An optical information recording and reproducing method described in (198) is characterized in that the light converging optical system has at least 2 diaphragms to regulate the image side numerical aperture in a plurality of information recording layers of the optical information recording medium. The effect of such the invention is the same as the invention described in (22).

An optical information recording and reproducing method described in (199) is characterized in that at least one of diaphragms is positioned between the final optical element and the optical information recording medium. The effect of such the invention is the same as the invention described in (23).

An optical information recording and reproducing method described in (200) is characterized in that at least one optical element of the light converging optical system is formed by etching. The effect of such the invention is the same as the invention described in (24).

In an optical information recording and reproducing method described in (201), the optical pick-up apparatus has the light source and the light converging optical system to

light converge the luminous flux emitted from the light source onto any one of information recording layers of the optical information recording medium having a laminated plurality of information recording layers, and the optical information recording and reproducing method is characterized in that, when the light converging optical system light converges the luminous flux whose image side numerical aperture is not smaller than 1.0, onto the information recording layer, by using the optical pick-up apparatus having the final optical element opposite to the optical information recording medium, spacing the interval not larger than the wavelength of the light source, the recording or reproducing of the information is to conducted onto the information recording layer. The effect of such the invention is the same as the invention described in (25).

An optical information recording and reproducing method described in (202) is characterized in that the light converging optical system has the final optical element opposite to the optical information recording medium, and the final optical surface of the final optical element is approximate to the surface of the optical information recording medium spacing the interval not larger than one fourth of the wavelength of the light source. The effect of

such the invention is the same as the invention described in (3).

An optical information recording and reproducing method described in (203) is characterized in that a plurality of light converging optical systems are provided, and each of light converging optical systems is used for the recording or reproducing of the information onto the respectively different information recording layers. The effect of such the invention is the same as the invention described in (4).

An optical information recording and reproducing method described in (204) is characterized in that the optical pick-up apparatus has a selection means for selecting the information recording layer onto which the recording or reproducing is to be conducted, from a laminated plurality of information recording layers, and the recording or reproducing of the information is conducted onto the information recording layer selected by the selection means. The effect of such the invention is the same as the invention described in (5).

An optical information recording and reproducing method described in (205) is characterized in that the light converging optical system has at least 2 final optical elements, and each of the final optical elements is used for

the recording or reproducing of the information onto the respectively different information recording layers, and when the selection means selects any one of the plurality of final optical elements, the recording or reproducing of the information is conducted onto the information recording layer corresponding to the selected final optical element. The effect of such the invention is the same as the invention described in (6).

An optical information recording and reproducing method described in (206) is characterized in that the selection means changes the wavelength of the light source, corresponding to each of laminated information recording layers onto which the recording or reproducing of the information is to be conducted. The effect of such the invention is the same as the invention described in (7).

An optical information recording and reproducing method described in (207) is characterized in that the selection means provides at least one optical element to vary the divergence degree or convergence degree of the incident light into the final optical element on the light source side of the final optical element, corresponding to each of laminated information recording layers onto which the recording or reproducing of the information is to be conducted. The

effect of such the invention is the same as the invention described in (8).

An optical information recording and reproducing method described in (208) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, has the positive lens group having the positive refractive power and the negative lens group having the negative refractive power, and at least one lens group of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (9).

An optical information recording and reproducing method described in (209) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, is composed of one positive lens and one negative lens, and at least one of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (10).

An optical information recording and reproducing method described in (210) is characterized in that the information recording medium includes the first recording layer and the second recording layer in the order of the distance nearer

from the final optical element, and when the recording or reproducing is conducted onto the first recording layer, the interval between the negative lens group and the positive lens group or the interval between the negative lens and the positive lens is more increased than the case where the recording or reproducing of the information is conducted onto the second recording layer. The effect of such the invention is the same as the invention described in (11).

An optical information recording and reproducing method described in (211) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, corrects the spherical aberration or axial chromatic aberration which hinders the recording or reproducing of the information, in the information recording layer onto which the recording or reproducing is to be conducted. The effect of such the invention is the same as the invention described in (12).

An optical information recording and reproducing method described in (212) is characterized in that the optical element to correct the variation of the spherical aberration and the axial chromatic aberration satisfies the following expression.

$$vdP > vdN \quad (1)$$

Where, vdP : the average of Abbe's number of the d line of all positive lenses including the positive lens (group), vdN : the average of Abbe's number of the d line of all negative lenses including the negative lens (group). The effect of such the invention is the same as the invention described in (13).

An optical information recording and reproducing method described in (212) is characterized in that the vdP and the vdN satisfy the following expressions.

$$vdP > 55 \quad (2)$$

$$vdN < 35 \quad (3)$$

The effect of such the invention is the same as the invention described in (14).

An optical information recording and reproducing method described in (214) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element can change the refractive index distribution. The effect of such the invention is the same as the invention described in (15).

An optical information recording and reproducing method described in (215) is characterized in that at least one

optical element constituting the light converging optical system has at least one aspherical optical surface. The effect of such the invention is the same as the invention described in (16).

An optical information recording and reproducing method described in (216) is characterized in that at least one optical element constituting the light converging optical system has a diffraction surface having a ring band-like diffraction structure. The effect of such the invention is the same as the invention described in (17).

An optical information recording and reproducing method described in (217) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose specific gravity is not larger than 2.0. The effect of such the invention is the same as the invention described in (18).

An optical information recording and reproducing method described in (218) is characterized in that at least one optical element constituting the light converging optical system is formed of the plastic material. The effect of such the invention is the same as the invention described in (19).

An optical information recording and reproducing method described in (219) is characterized in that at least one

optical element constituting the light converging optical system is formed of the material whose saturation water absorption is not larger than 0.5 %. The effect of such the invention is the same as the invention described in (20).

An optical information recording and reproducing method described in (220) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose internal transmissivity at the 3 mm thickness to the light of the oscillation wavelength of the light source is not smaller than 85 %. The effect of such the invention is the same as the invention described in (21).

An optical information recording and reproducing method described in (221) is characterized in that the light converging optical system has at least 2 diaphragms to regulate the image side numerical aperture in a plurality of information recording layers of the optical information recording medium. The effect of such the invention is the same as the invention described in (22).

An optical information recording and reproducing method described in (222) is characterized in that at least one diaphragm of the diaphragms is positioned between the final optical element and the optical information recording medium.

The effect of such the invention is the same as the invention described in (23).

An optical information recording and reproducing method described in (223) is characterized in that at least one optical element of the light converging optical system is formed by etching. The effect of such the invention is the same as the invention described in (24).

An optical information recording and reproducing method described in (224) is characterized in that the optical pick-up apparatus which has the light source and the light converging optical system to light converge the luminous flux emitted from the light source onto any one of information recording layers of the optical information recording medium having a transparent substrate whose thickness is not smaller than the wavelength of the light source on the outermost information recording layer, and when, by using the optical pick-up apparatus having the final optical element opposite to the transparent substrate spacing the interval not larger than the wavelength of the light source, the light converging optical system light-converges the luminous flux whose image side numerical aperture is not smaller than 1.0 onto the information recording layer, the recording or reproducing of the information is conducted onto the information recording

layer. The effect of such the invention is the same as the invention described in (48).

An optical information recording and reproducing method described in (225) is characterized in that the final optical surface of the final optical element is approximate to the surface of the optical information recording medium spacing the interval not larger than one fourth of the wavelength of the light source. The effect of such the invention is the same as the invention described in (3).

An optical information recording and reproducing method described in (226) is characterized in that a plurality of light converging optical systems are provided, and each of light converging optical systems is used for the recording or reproducing of the information onto the respectively different information recording layers. The effect of such the invention is the same as the invention described in (4).

An optical information recording and reproducing method described in (227) is characterized in that the optical pick-up apparatus has a selection means for selecting the information recording layer onto which the recording or reproducing is to be conducted, from a laminated plurality of information recording layers, and the recording or reproducing of the information is conducted onto the

information recording layer selected by the selection means. The effect of such the invention is the same as the invention described in (5).

An optical information recording and reproducing method described in (228) is characterized in that the light converging optical system has at least 2 final optical elements, and each of the final optical elements is used for the recording or reproducing of the information onto the respectively different information recording layers, and when the selection means selects any one of the plurality of final optical elements, the recording or reproducing of the information is conducted onto the information recording layer corresponding to the selected final optical element. The effect of such the invention is the same as the invention described in (6).

An optical information recording and reproducing method described in (229) is characterized in that the selection means changes the wavelength of the light source, corresponding to each of laminated information recording layers onto which the recording or reproducing of the information is to be conducted. The effect of such the invention is the same as the invention described in (7).

An optical information recording and reproducing method described in (230) is characterized in that the selection means provides at least one optical element to vary the divergence degree or convergence degree of the incident light into the final optical element on the light source side of the final optical element, corresponding to each of laminated information recording layers onto which the recording or reproducing of the information is to be conducted. The effect of such the invention is the same as the invention described in (8).

An optical information recording and reproducing method described in (231) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, has the positive lens group having the positive refractive power and the negative lens group having the negative refractive power, and at least one lens group of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (9).

An optical information recording and reproducing method described in (232) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, is

composed of one positive lens and one negative lens, and at least one of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (10).

An optical information recording and reproducing method described in (233) is characterized in that the information recording medium includes the first recording layer and the second recording layer in the order of the distance nearer from the final optical element, and when the recording or reproducing is conducted onto the first recording layer, the interval between the negative lens group and the positive lens group or the interval between the negative lens and the positive lens is more increased than the case where the recording or reproducing of the information is conducted onto the second recording layer. The effect of such the invention is the same as the invention described in (11).

An optical information recording and reproducing method described in (234) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, corrects the spherical aberration or axial chromatic aberration which hinders the recording or reproducing of the information, in the information recording layer onto which

the recording or reproducing is to be conducted. The effect of such the invention is the same as the invention described in (12).

An optical information recording and reproducing method described in (235) is characterized in that the optical element to correct the variation of the spherical aberration and the axial chromatic aberration satisfies the following expression.

$$vdP > vdN \quad (1)$$

Where, vdP : the average of Abbe's number of the d line of all positive lenses including the positive lens (group), vdN : the average of Abbe's number of the d line of all negative lenses including the negative lens (group). The effect of such the invention is the same as the invention described in (13).

An optical information recording and reproducing method described in (236) is characterized in that the vdP and the vdN satisfy the following expressions.

$$vdP > 55 \quad (2)$$

$$vdN < 35 \quad (3)$$

The effect of such the invention is the same as the invention described in (14).

An optical information recording and reproducing method described in (237) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element can change the refractive index distribution. The effect of such the invention is the same as the invention described in (15).

An optical information recording and reproducing method described in (238) is characterized in that at least one optical element constituting the light converging optical system has at least one aspherical optical surface. The effect of such the invention is the same as the invention described in (16).

An optical information recording and reproducing method described in (239) is characterized in that at least one optical element constituting the light converging optical system has a diffraction surface having a ring band-like diffraction structure. The effect of such the invention is the same as the invention described in (17).

An optical information recording and reproducing method described in (240) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose specific gravity is

not larger than 2.0. The effect of such the invention is the same as the invention described in (18).

An optical information recording and reproducing method described in (241) is characterized in that at least one optical element constituting the light converging optical system is formed of the plastic material. The effect of such the invention is the same as the invention described in (19).

An optical information recording and reproducing method described in (242) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose saturation water absorption is not larger than 0.5 %. The effect of such the invention is the same as the invention described in (20).

An optical information recording and reproducing method described in (243) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose internal transmissivity at the 3 mm thickness to the light of the oscillation wavelength of the light source is not smaller than 85 %. The effect of such the invention is the same as the invention described in (21).

An optical information recording and reproducing method described in (244) is characterized in that the light

converging optical system has at least 2 diaphragms to regulate the image side numerical aperture in a plurality of information recording layers of the optical information recording medium. The effect of such the invention is the same as the invention described in (22).

An optical information recording and reproducing method described in (245) is characterized in that at least one diaphragm of the diaphragms is positioned between the final optical element and the optical information recording medium. The effect of such the invention is the same as the invention described in (23).

An optical information recording and reproducing method described in (246) is characterized in that at least one optical element of the light converging optical system is formed by etching. The effect of such the invention is the same as the invention described in (24).

In an optical information recording and reproducing method described in (247), in which, by using the optical pick-up apparatus which has the light source and the light converging optical system to light converge the luminous flux emitted from the light source onto any one of information recording layers of the optical information recording medium having a plurality of laminated information recording layers,

the recording or reproducing of the information is conducted onto the optical information recording medium, the optical information recording and reproducing method is characterized in that, by a predetermined optical pick-up element provided between the light source and the final optical element of the light converging optical system, the information recording layer onto which the recording or reproducing of the information is to be conducted is changed. The effect of such the invention is the same as the invention described in (71).

An optical information recording and reproducing method described in (248) is characterized in that the optical element to change the information recording layer onto which the recording or reproducing of the information is to be conducted, varies the divergence degree or convergence degree of the incident light into the final optical element. The effect of such the invention is the same as the invention described in (8).

An optical information recording and reproducing method described in (249) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, has the positive lens group having the positive refractive power and

the negative lens group having the negative refractive power, and at least one lens group of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (9).

An optical information recording and reproducing method described in (250) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, is composed of one positive lens and one negative lens, and at least one of them is a displaceable movable element. The effect of such the invention is the same as the invention described in (10).

An optical information recording and reproducing method described in (251) is characterized in that the information recording medium includes the first recording layer and the second recording layer in the order of the distance nearer from the final optical element, and when the recording or reproducing is conducted onto the first recording layer, the interval between the negative lens group and the positive lens group or the interval between the negative lens and the positive lens is more increased than the case where the recording or reproducing of the information is conducted onto

the second recording layer. The effect of such the invention is the same as the invention described in (11).

An optical information recording and reproducing method described in (252) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element, corrects the spherical aberration or axial chromatic aberration which hinders the recording or reproducing of the information, in the information recording layer onto which the recording or reproducing is to be conducted. The effect of such the invention is the same as the invention described in (12).

An optical information recording and reproducing method described in (253) is characterized in that the optical element to correct the variation of the spherical aberration and the axial chromatic aberration satisfies the following expression.

$$vdP > vdN \quad (1)$$

Where, vdP : the average of Abbe's number of the d line of all positive lenses including the positive lens (group), vdN : the average of Abbe's number of the d line of all negative lenses including the negative lens (group). The effect of

such the invention is the same as the invention described in (13).

An optical information recording and reproducing method described in (254) is characterized in that the value vdP and the value vdN satisfy the following expressions.

$$vdP > 55 \quad (2)$$

$$vdN < 35 \quad (3)$$

The effect of such the invention is the same as the invention described in (14).

An optical information recording and reproducing method described in (255) is characterized in that the optical element to vary the divergence degree or convergence degree of the incident light into the final optical element can change the refractive index distribution. The effect of such the invention is the same as the invention described in (15).

An optical information recording and reproducing method described in (256) is characterized in that at least one optical element constituting the light converging optical system has at least one aspherical optical surface. The effect of such the invention is the same as the invention described in (16).

An optical information recording and reproducing method described in (261) is characterized in that at least one optical element constituting the light converging optical system is formed of the material whose internal transmissivity at the 3 mm thickness to the light of the oscillation wavelength of the light source is not smaller than 85 %. The effect of such the invention is the same as the invention described in (21).

An optical information recording and reproducing method described in (262) is characterized in that the light converging optical system has at least 2 diaphragms to regulate the image side numerical aperture in a plurality of information recording layers of the optical information recording medium. The effect of such the invention is the same as the invention described in (22).

An optical information recording and reproducing method described in (263) is characterized in that at least one diaphragm of the diaphragms is positioned between the final optical element and the optical information recording medium. The effect of such the invention is the same as the invention described in (23).

An optical information recording and reproducing method described in (264) is characterized in that at least one

optical element of the light converging optical system is formed by etching. The effect of such the invention is the same as the invention described in (24).

In the present specification, the phrase of the recording or reproducing of the information onto the information recording layer, means, when the information recording layer is structured by the layer through which the light can be transmitted, and information recording surface, the information recording light is irradiated onto the information recording surface through the layer through which the light can be transmitted, and the recording of the information is conducted onto that position, or the reproducing of the information is conducted from that position.

The diffraction surface used in the present specification means that the surface of the optical element, for example, on the surface of the lens, a relief is provided, and a mode (or a surface) in (or on) which the angle of the light is changed by the diffraction, and when there is, on one optical surface, an area in which the diffraction is generated and not generated, it means the area in which the diffraction is generated. As the shape of the relief, for example, on the surface of the optical element,

it is formed as an almost concentric circle-like ring band around the optical axis, and when viewing its cross section on the surface including the optical axis, it is well known that each ring band has a saw-toothed shape, and it includes such the shape. Specifically, such the saw-toothed ring band structure is preferable.

The light converging optical system used in the present specification means the optical element group to light converge the luminous flux emitted from the light source, or optical element group concerning the light convergence (for example, including a beam expander or negative lens of the aberration correction system). The final optical element means the optical element including in the light converging optical system which is most approximate to or in contact with the optical information recording medium.

The beam expander used in the present specification means at least one optical element such as a lens is displaceable, and thereby, the divergent angle (divergent action, convergent action are included) can be changed, and when almost parallel luminous flux is incident to it, it means a collective body of optical elements such as lenses (optical element group such as lens group) from which almost parallel light can be emitted. It is preferable that a

plurality of optical elements such as these lenses are integrated, and when at least the optical element such as one lens is structured to be displaceable, the drive means such as a displacing apparatus to practically displace it, may not be included as a beam expander.

In the present specification, as the optical information recording medium, it may be a disk-like medium which rotates around the center of the disk as the axis, or may not be so. Further, as the recording or reproducing system of the information onto the information recording layer, it may be a system using the phase change recording system such as a CD or DVD, or when it is a system in which the recording or reproducing is conducted by using the converged light, it may not be limited to that.

In the present specification, the recording or reproducing of the information means that the information is recorded on the information recording surface of the optical information recording medium as described above, or the information recorded on the information recording surface is reproduced. The optical pick-up apparatus of the present invention may be used for conducting only recording or only reproducing, and may be used for conducting both of the recording and reproducing. Further, it may be used for

conducting the recording onto one optical information recording medium, and conducting the reproducing onto another optical information recording medium, and it may be used for conducting the recording or reproducing onto an optical information recording medium, and conducting the recording and reproducing onto another optical information recording medium. In this connection, the reproduction used herein includes also only the reading of the information.

The optical pick-up apparatus of the present invention can be mounted onto the recording and/or reproducing apparatus of the digital data including the voice and image of each kind of player or drive, or a media equipment in which these are assembled, personal computer, and other information devices.

(Embodiment of the invention)

Referring to the drawings, an embodiment of the invention will be described below. Fig. 2 is an outline structural view of an optical pick-up apparatus by which the recording or reproducing of the information can be conducted onto a multi-layer type optical information recording medium which is an embodiment of the present invention. In Fig. 2, the divergent angle of the information recording light emitted from the first light source 11 is changed by a

coupling lens 15, and after the light passes through a beam splitter 61, the divergent angle is changed by a coupling lens 21, and after passed through an $1/4$ wavelength plate 71, the light passes through a beam splitter 62, and passes through a negative lens 5 and positive lens which are displaceable in the optical axis direction, and enters into an objective lens 1 stopped down by a diaphragm 8A. In the present embodiment, the objective lens 1 is structured by the second lens 1a and the solid immersion lens 1b which is a final optical element. The information recording light emitted from the objective lens 1 is not stopped down by the diaphragm 8B arranged on the emitting surface 1b of the solid immersion lens, and image-formed onto the first recording layer 23a of a multi-layer (in which a plurality of (herein, 2) information recording layers are provided) type optical information recording medium 23, and the information is recorded or reproduced. It is preferable that the second lens 1a of the objective lens 1 and the solid immersion lens 1b which is a SIL (Solid Immersion Lens) (or another optical element), are formed of the plastic material whose saturation water absorption is not larger than 5 %. The beam expander is structured by the negative lens 5, positive lens 6, and an actuator 7. Further, a light converging optical system is

composed of the coupling lens 15, 21, negative lens 5, positive lens 6, and objective lens 1.

The light reflected by the first recording layer 23a of the optical information recording medium 23 goes the same light path, and is reflected by the beam splitter 62, and image-formed onto the light receiving surface of a light detector 41 through a cylindrical lens 9 and concave lens 16.

On the one hand, the information recording light irradiated from the second light source 12, passes through a hologram 17, and the divergent angle is changed by a coupling lens 22, and after the light passes through the $1/4$ wavelength plate, it is reflected by a beam splitter 62, and by an actuator 7, it passes the displaceable negative lens 5 and positive lens 4, and is not stopped down by the diaphragm 8A, and enters into the objective lens 1. The information recording light emitted from the objective lens 1 is image-formed onto the second recording layer 23b after it is stopped down by the diaphragm 8B arranged on the emitting surface 1b of the solid immersion lens, and the recording or reproducing of the information is conducted.

The light reflected by the second recording layer 23b of the optical information recording medium 23 passes the same light path and reflected by the beam splitter 62, and

image-formed onto the light receiving surface of the light detector 42 through the $1/4$ wavelength plate 72, coupling lens 22, and hologram 17 which separates the reflected light.

Herein, the interval between the solid immersion lens 1b and the optical information recording medium 23 is, as shown in Fig. 1, not larger than $1/4$ of the wavelength of the information recording light. Accordingly, according to the present embodiment, by using the near field effect, the recording or reproducing of the information can be conducted onto the information recording surface of each of information recording layers, through a protective layer (not shown) of the optical information recording medium 23 by the information recording light whose image side numerical aperture (NA) is not smaller than 1, including the evanescent light from the solid immersion lens 1b.

Further, in the present embodiment, when the negative lens 5 is moved in the optical axis direction by the actuator 7, the recording or reproducing of the information may be conducted onto the different information recording layers. Specifically, when the interval between the negative lens 5 and positive lens 6b is increased, the recording or reproducing of the information is conducted onto the information recording layer 23a nearer to the solid immersion

lens 1b, and when the interval between the negative lens 5 and positive lens 6 is reduced, the recording or reproducing of the information can be conducted onto the information recording layer 23b farther from the solid immersion lens 1b. In the present embodiment, a selection means is structured by beam expanders (5, 6, 7) which function as a transfer apparatus to change the divergent angle of the luminous flux, and further, function as the optical element to change the information recording layers onto which the recording or reproducing of the information is to be conducted.

Further, in the present embodiment, corresponding to a fact that the wavelengths of the first light source 11 and the second light source 12 are different, by using that the focal distance of the objective lens changes, the recording or reproducing of the information may be conducted onto the different information recording layers thereby. In such the case, the selection means used in the present invention means that the first light source 11, and second light source 12, and each of optical systems through which the information recording light irradiated from them passes. Such the optical system is, in the present embodiment, used as a common in a portion, however, it may be an independently separated one. However, when the optical element constituting each optical

system is formed of a material whose internal transmissivity is not smaller than 85 % at the 3 mm thickness, the loss at the time of light transmission can be preferably suppressed.

In this connection, in order to selectively conducting the recording or reproducing of the information onto each of information recording layers 23a, 23 b of the optical information recording medium 23, it is considered that, for example, 2 of the second lenses 1a of the objective lens, or the solid immersion lenses 1b are prepared, and are separately used corresponding to the information recording layers onto which the recording or reproducing of the information is required to be conducted.

As a means for correcting the variation of the spherical aberration and axial chromatic aberration, when the optical surface of the second lens 1a of the objective lens 1 is formed into an aspherical surface, the aberration becomes fine, and further, when the diffraction ring band is formed on the optical surface, the axial chromatic aberration correction or the temperature correction becomes possible. However, such the aspherical surface or diffraction ring band may be provided on another optical element (the coupling lens 15, 21, 22, negative lens 5, positive lens 6).

When the negative lens 5 and positive lens 6 are used as a means for correcting the variation of the spherical aberration and axial chromatic aberration, it may be preferable when the following expression is satisfied.

$$vdP > vdN \quad (1)$$

Particularly, it is preferable when the following expressions are satisfied.

$$vdP > 55 \quad (2)$$

$$vdN < 35 \quad (3)$$

Where, vdP : the average of Abbe's number of the d line of the positive lens 6, and vdN : the average of Abbe's number of the d line of the negative lens 5.

Fig. 3 is an outline structural view showing the optical system according to the second embodiment. In the present embodiment, it is different that, instead of the beam expander shown in Fig. 2, the optical element SE is used and the light converging optical system is structured. The optical system SE as the changing means is an element by which the refractive index distribution can be changed, and in Fig. 3, it is arranged on the light source (not shown) side of the solid immersion lens 1b.

The optical element SE is formed in such a manner that, as shown in Fig. 3, for example, an electrode layers a, b, and c which are electrically connected and optically transparent, and a refractive index changeable layers d, e, which are electrically insulated from the electrode layers a, b, c, and by which the refractive index distribution is changed corresponding to the applied voltage, are alternately laminated, and the optically transparent electrodes a, b, c are divided into a plurality of areas.

Herein, by using the optical element SE, to select the information recording layers of the multi-layer type optical information recording medium 23, the voltage is applied onto the electrode layers a, b, c by the drive apparatus DS of the optical element SE, and when the refractive index of the refractive index changeable layers d, e is changed corresponding to the place, and the phase of the emitted light from the optical element SE toward the solid immersion lens 1b is controlled, the divergence degree or convergence degree of the incident light into the solid immersion lens 1b can be changed. When the divergence degree or convergence degree of the incident light into the solid immersion lens 1b is changed, the image formation position of the light which is light converged by the solid immersion lens 1b is changed,

thereby, the information recording layer onto which the information is recorded or reproduced can be changed.

Fig. 4 is an outline structural view showing the optical system according to the third embodiment. In the present embodiment, the optical element SE as the changing means is provided with a liquid crystal element a' in which the liquid crystal molecule is arranged aligning in the arbitrary X direction, in the vertical surface to the optical axis, and a liquid crystal element b' in which the liquid crystal molecule is arranged aligning in the Y direction perpendicular to the X direction, in the vertical surface to the optical axis, and by the liquid crystal element a', b', the glass substrate c' is nipped, and alternately laminated, and a 1/2 wavelength plate d' is arranged between the inside glass substrates c'.

Herein, by using the optical element SE, to select the information recording layer of the multi-layer type optical information recording medium 23, when the voltage is applied onto the liquid crystal elements a', b' by the drive apparatus DS of the optical element SE, and the X direction component and Y direction component of the phase of the emitted light from the optical element SE are independently controlled, the divergence degree or convergence degree of

the incident light into the solid immersion lens 1b can be changed. When the divergence degree or convergence degree of the incident light into the solid immersion lens 1b is changed, the image formation position of the light which is light converged by the solid immersion lens 1b is changed, thereby, the information recording layer onto which the information is recorded or reproduced can be changed.

As described above, according to the optical element SE shown in Figs. 3 and 4, when the refractive index distribution is generated corresponding to the voltage impression, thereby, the layer which is an object of the recording or reproducing is changed, the light converging optical system not having movable parts and having a mechanically simple structure can be provided. In this connection, as it is well known, by the optical element SE, the variation of the spherical aberration can also be corrected.

Fig. 5 is a view showing the relationship between the final optical element and the diaphragm, according to the fourth embodiment. As shown in Fig. 5(a), the information recording light by which the information is recorded or reproduced onto the first information recording layer 23a (Fig. 2) of the information recording layers 23 is stopped

down by the diaphragm 108A arranged on the incident surface side of a single dioptric SIM (Solid Immersion Mirror, hereinafter, called SIM), 1b' as the final optical element supported through an interval not larger than $1/4$ of the using wavelength to the optical information recording medium 23, and as shown in Fig 5(b), the information recording light by which the information is recorded or reproduced onto the second information recording layer 23b (Fig. 2) of the information recording layers 23 is stopped down by the diaphragm (transmission opening portion) 108B arranged between the SIM 1b' and optical information recording medium 23.

Fig. 6 is a view showing the relationship between the objective lens and the diaphragm according to the fifth embodiment. As shown in Fig. 6(a), the information recording light by which the information is recorded or reproduced onto the first information recording layer 23a (Fig. 2) of the information recording layers 23 is stopped down by the diaphragm 208A arranged on the incident surface side of the second lens 1a of the objective lens, and as shown in Fig. 5(b), the information recording light by which the information is recorded or reproduced onto the second information recording layer 23b (Fig. 2) of the information

recording layers 23 is stopped down by a diaphragm (transmission opening portion) 208B arranged between the solid immersion lens 1b and the optical information recording medium 23. According to the 4 and 5 embodiments described above, the image side numerical aperture (NA) in the case where the information is recorded or reproduced onto each of information recording layers can be respectively independently set when the diameters of the apertures of the diaphragms 108A and 108B or 208A and 208B are adjusted.

Fig. 7 is a view showing a light converging optical system according to the sixth embodiment. The light converging optical system of the present embodiment is structured by a SIM 1b' supported through the interval not larger than $1/4$ of the using wavelength to the multi-layer type optical information recording medium 23, and a beam expander structured by respectively one positive lens 105 and one negative lens 106 from the light source side, not shown. When, from the position shown in Fig. 7(a), only the positive lens 105 of the beam expander is moved along the optical axis to the SIM 1b' side (position shown in Fig. 7(b)), the divergence degree of the incident light into the SIM 1b' is changed, thereby, the information recording layer of the optical information recording medium 23 which is an object to

record or reproduce the information, is changed. In this connection, the order of the positive lens 105 and negative lens 106 is not also concerned about the order of the negative lens and positive lens from the light source.

Fig. 8 is a view showing a light converging optical system according to the seventh embodiment. The light converging optical system of the present embodiment is structured by a solid immersion lens 1b supported through the interval of $1/4$ of the using wavelength to the multi-layer type optical information recording medium 23, and a beam expander structured by respectively one positive lens 205 and one negative lens 206 from the light source side, not shown. When, from the position shown in Fig. 8(a), only the positive lens 205 of the beam expander is moved along the optical axis to the solid immersion lens 1b side (position shown in Fig. 8(b)), the divergence degree of the incident light into the solid immersion lens 1b is changed, thereby, the information recording layer of the optical information recording medium 23 which is an object to record or reproduce the information, is changed.

Fig. 9 is a view showing a light converging optical system according to the eighth embodiment. The light converging optical system of the present embodiment is

structured by a solid immersion lens 1b supported through the interval of $1/4$ of the using wavelength to the multi-layer type optical information recording medium 23, and a beam expander structured by the second lens 1a and diaphragm 308A, and respectively one negative lens 305 and one positive lens 306 from the light source side, not shown. When, from the position shown in Fig. 9(a), only the negative lens 305 of the beam expander is moved along the optical axis to the solid immersion lens 1b side (position shown in Fig. 9(b)), the divergence degree of the incident light into the solid immersion lens 1b is changed, thereby, the information recording layer of the optical information recording medium 23 which is an object to record or reproduce the information, is changed.

Fig. 10 is a view showing an objective lens composition according to another embodiment. In Fig. 10, the solid immersion lens 1b is a super semi-spherical lens, and structured so that the following aplanatic conditional expressions are realized. Further, the light converging point of the solid immersion lens 1b is at just an intermediate between 2 recording layers.

$$S = r(1 + (n' / n)) \quad (4)$$

$$S' = r(1 + (n / n')) \quad (5)$$

Where, S : the distance from the image forming point P of the second lens 1a to the apex V of the solid immersion lens 1b, S' : the distance from the image forming point P' of the composite system to the apex V of the solid immersion lens 1b, r : the radius of curvature of the solid immersion lens 1b, n : the refractive index of the air, and n' : the refractive index of the solid immersion lens 1b.

Herein, in Fig. 10, the numerical aperture (NA) of the second lens 1a is $\sin \theta$ (θ is a half angle of the maximum conical angle of the image space of the objective lens), and NA' in the composition system of the objective lens composed of the second lens 1a and the solid immersion lens 1b can be expressed by $(n')^2 \cdot \sin \theta$ (in this connection, n' is the refractive index of the solid immersion lens 1b). Further, when the aberration of the objective lens is finely corrected, this solid immersion lens 1b can realize the light convergence of almost no aberration. Accordingly, when the objective lens for the existing CD, DVD is used as the objective lens, the optical system whose image side numerical aperture (NA) is not smaller than 1, and whose aberration is finely corrected, can be easily obtained.

According to the optical pick-up apparatus and objective lens of the present invention, the large capacity of optical information recording and/or reproduction, which is more increased than the conventional one, together with both the area recording density and volume recording density of the optical information recording medium, can be conducted.